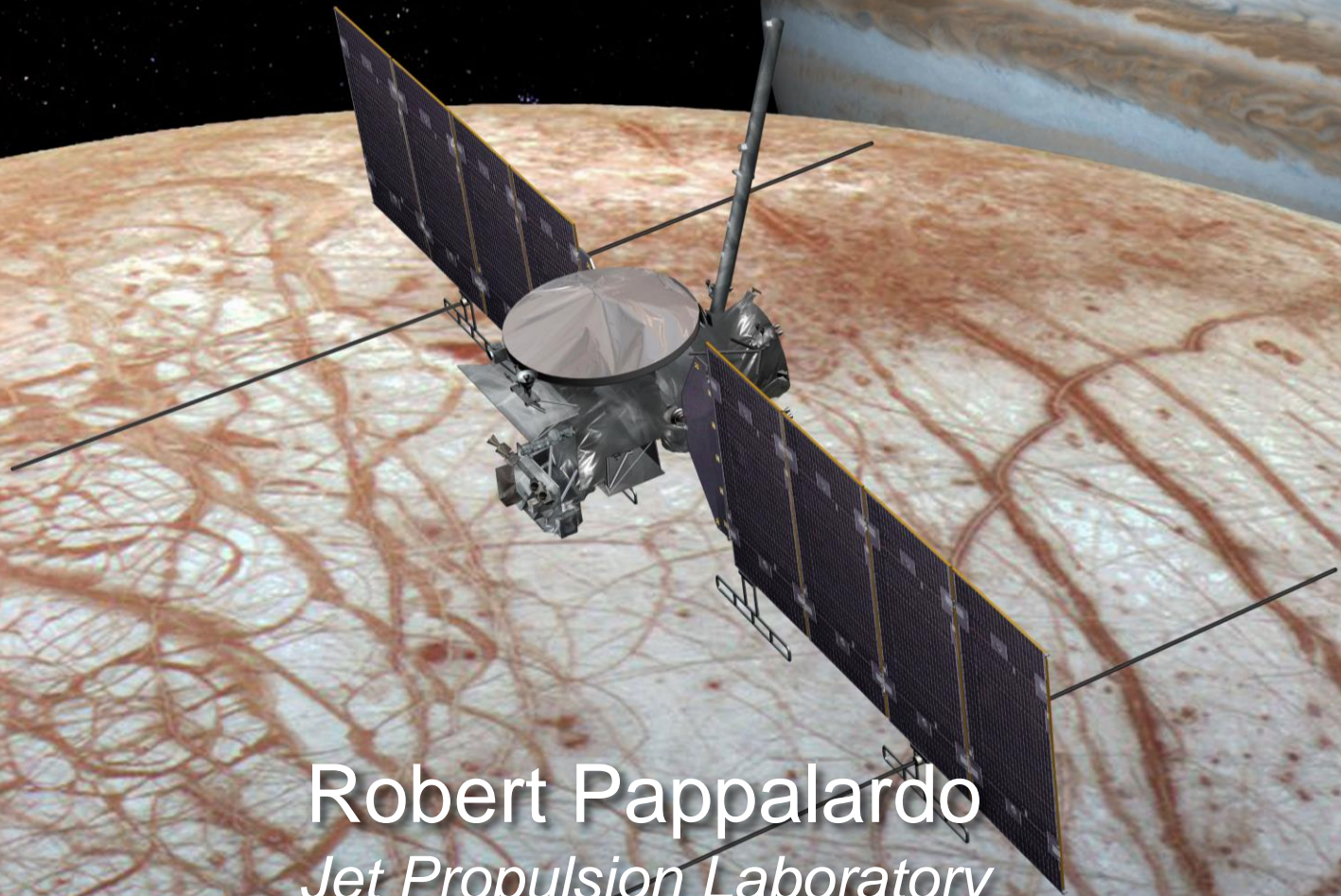


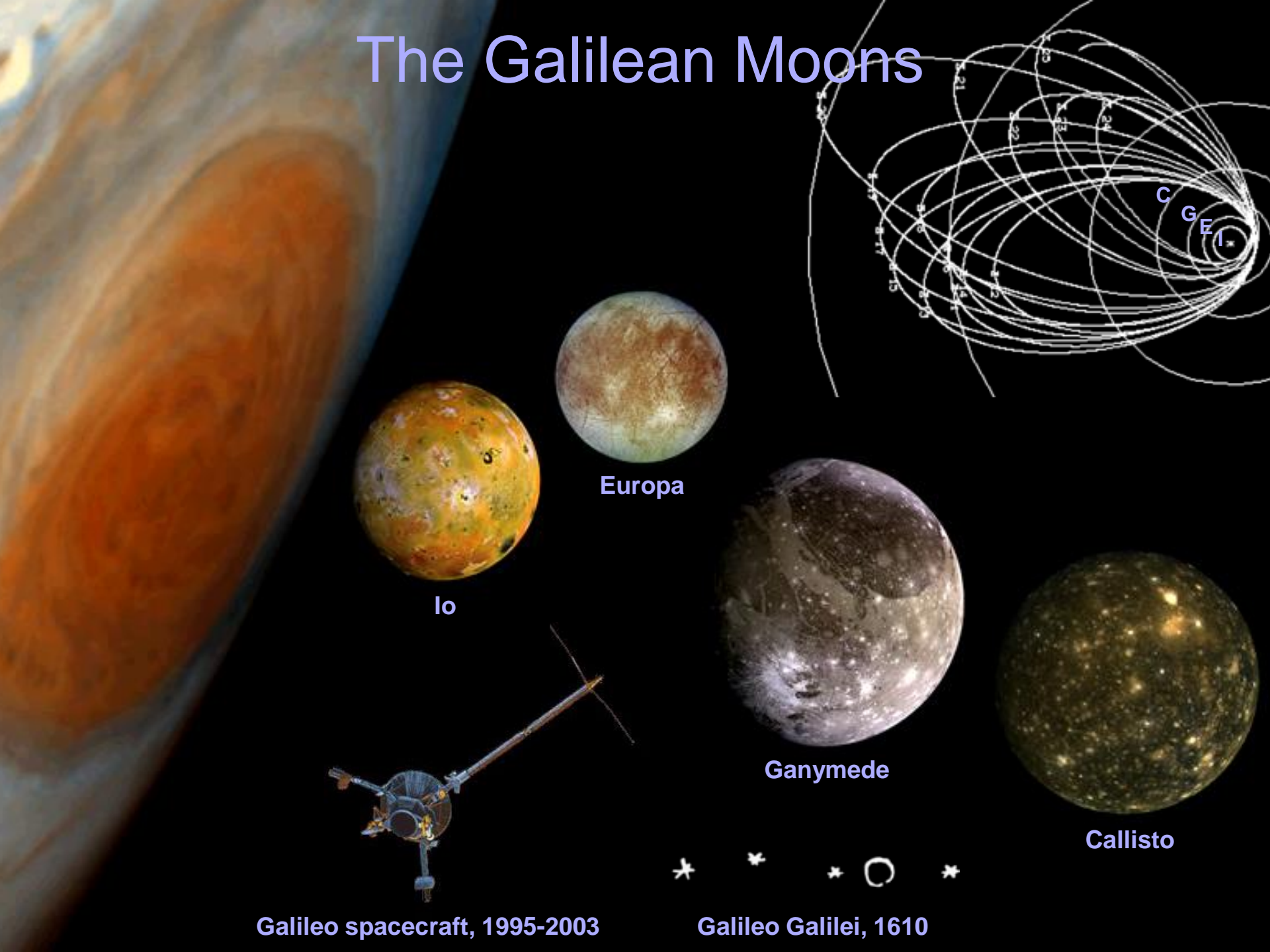
Exploring Europa: A Potentially Habitable World



Robert Pappalardo
Jet Propulsion Laboratory
California Institute of Technology

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The Galilean Moons



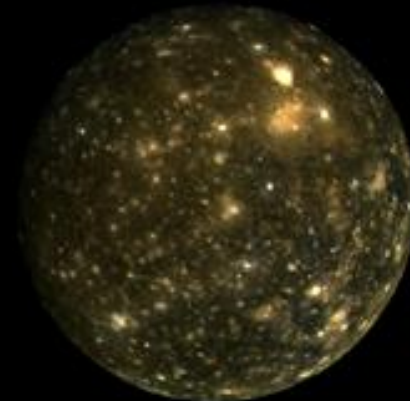
Io



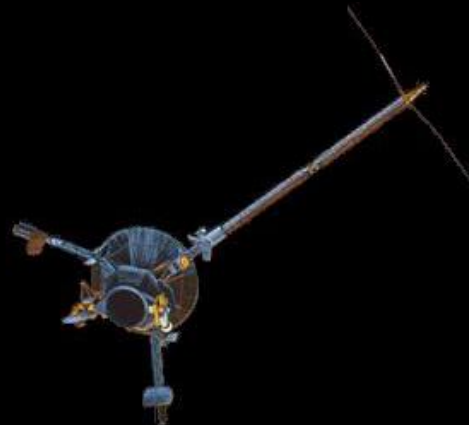
Europa



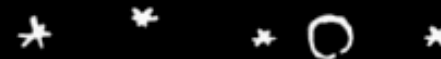
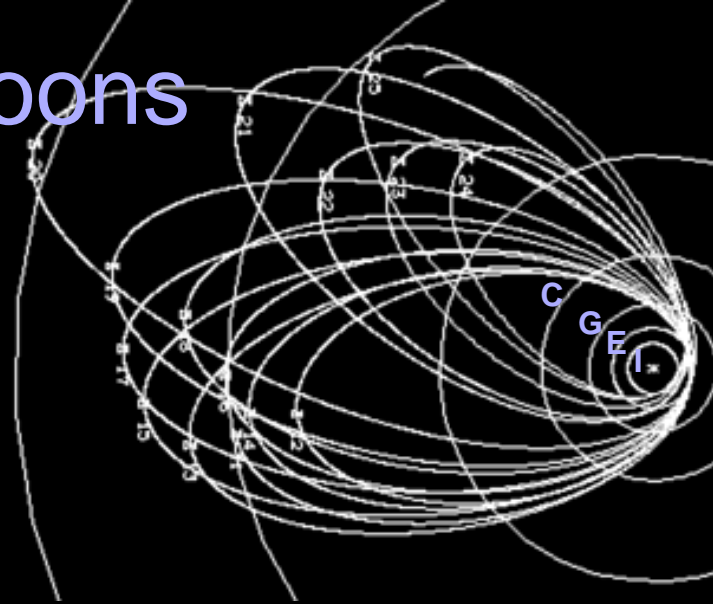
Ganymede



Callisto

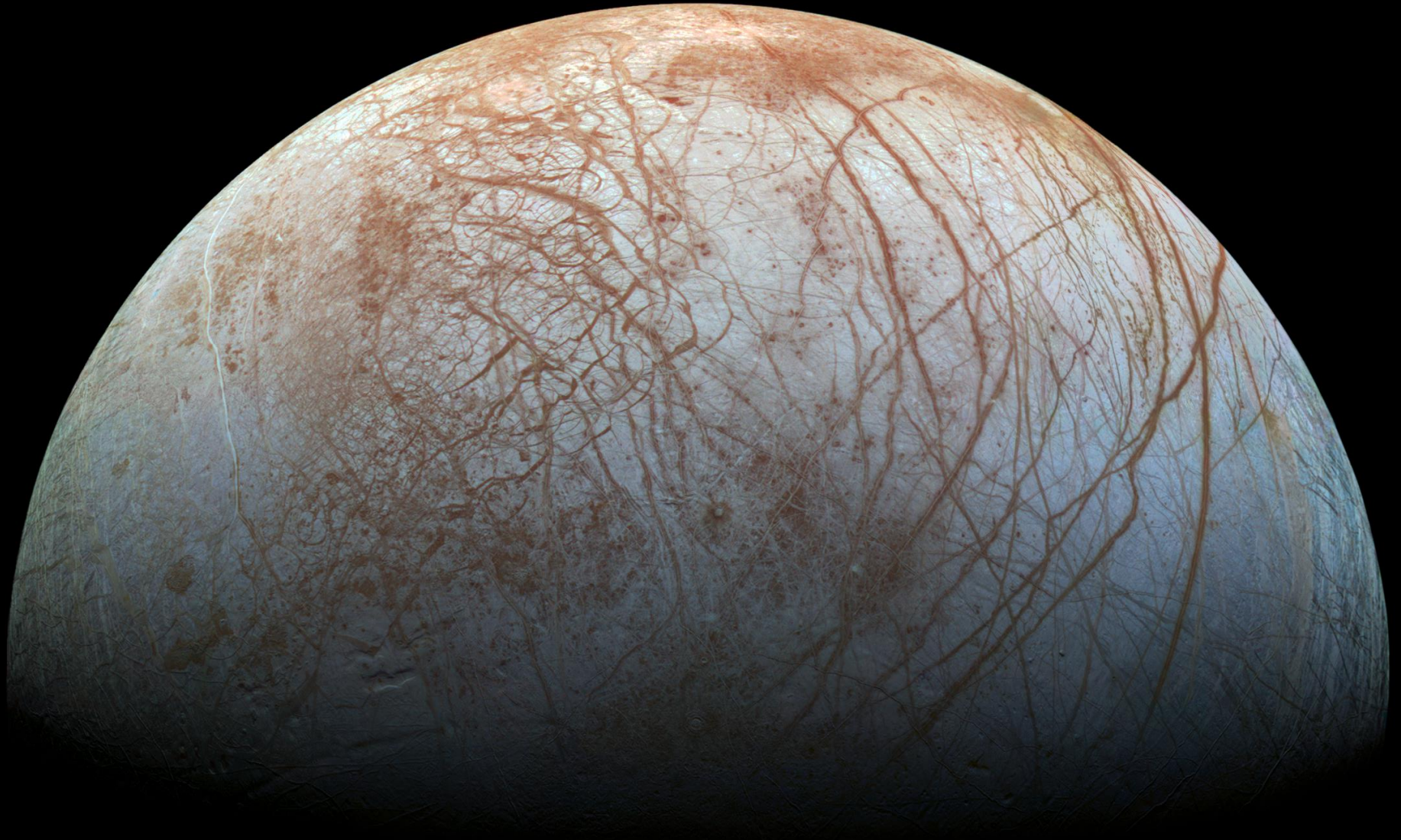


Galileo spacecraft, 1995-2003



Galileo Galilei, 1610

Europa



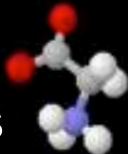
The Planetary Ingredients for Life



water



essential
elements



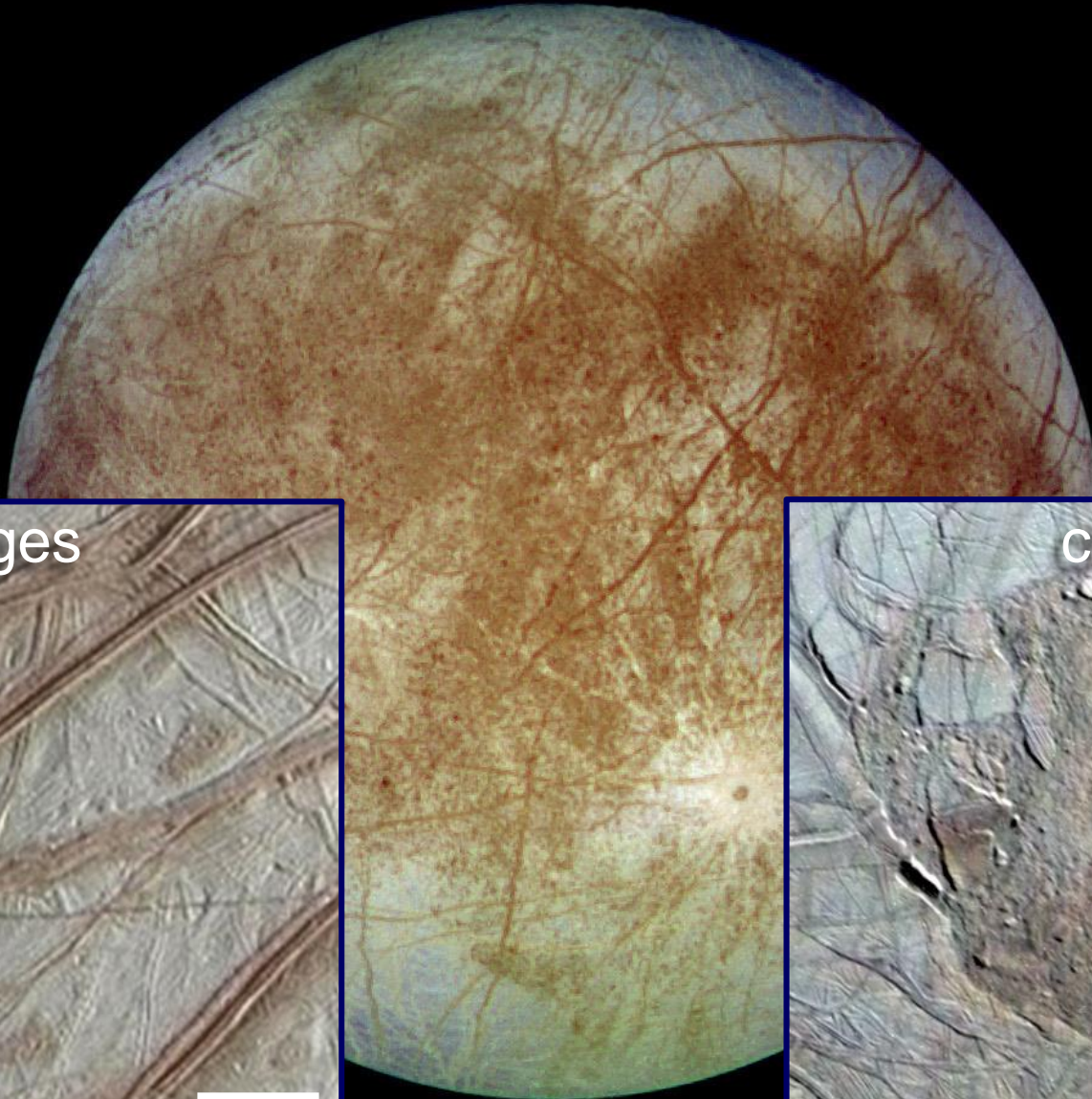
chemical
energy



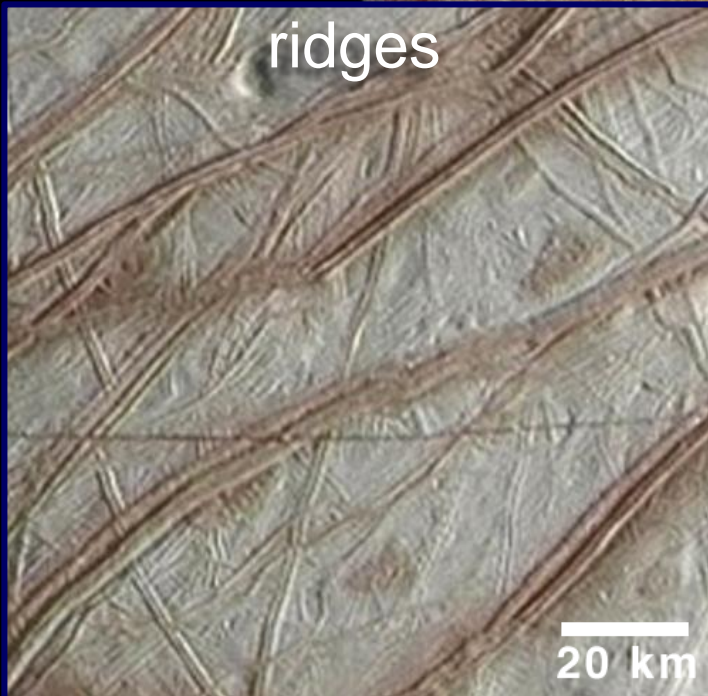
stability



Europa's Surface

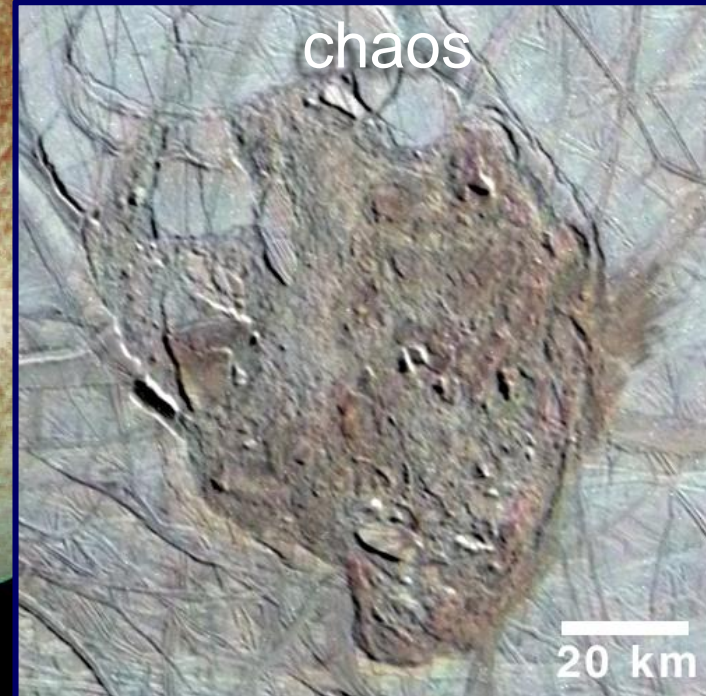


ridges



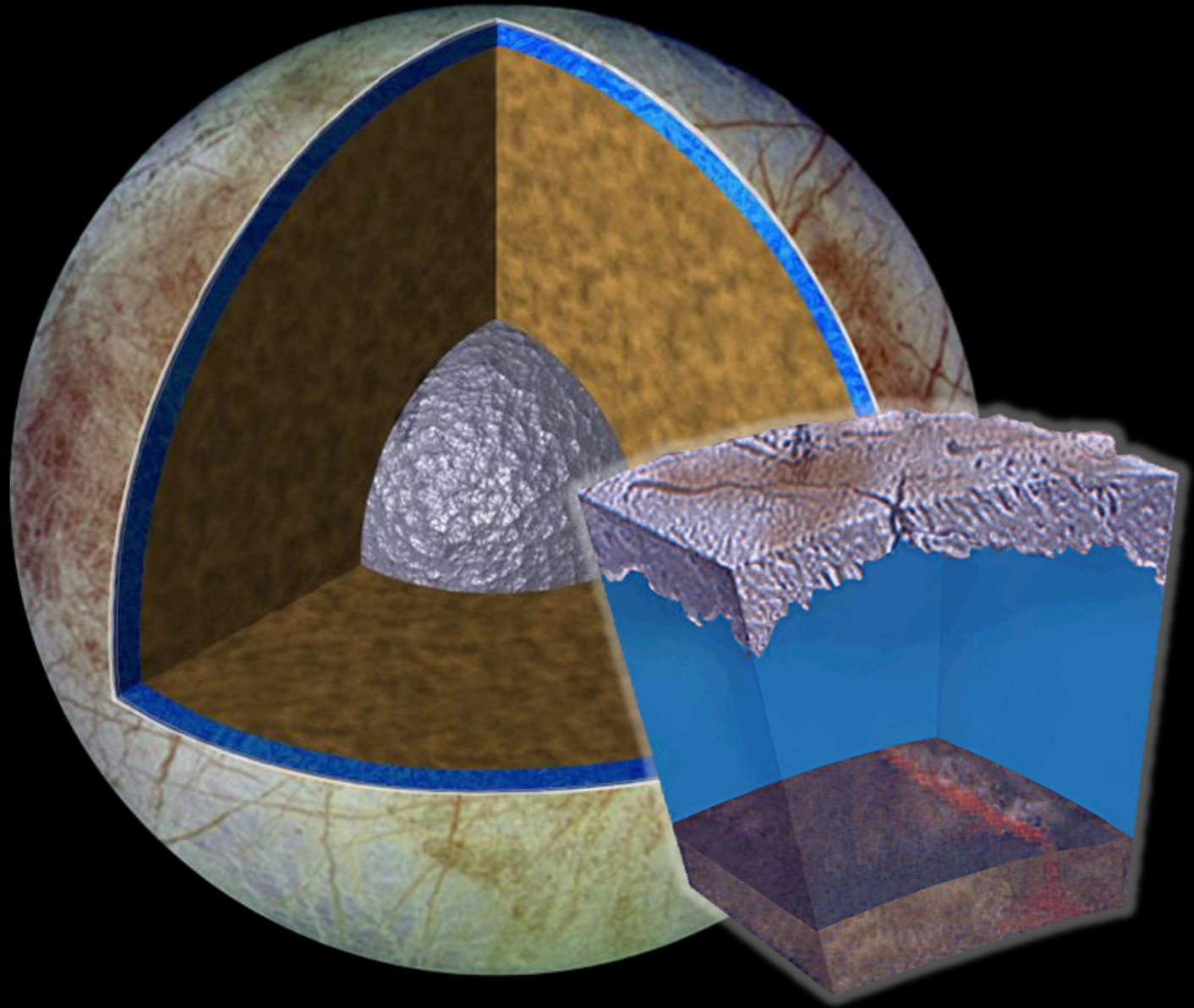
20 km

chaos

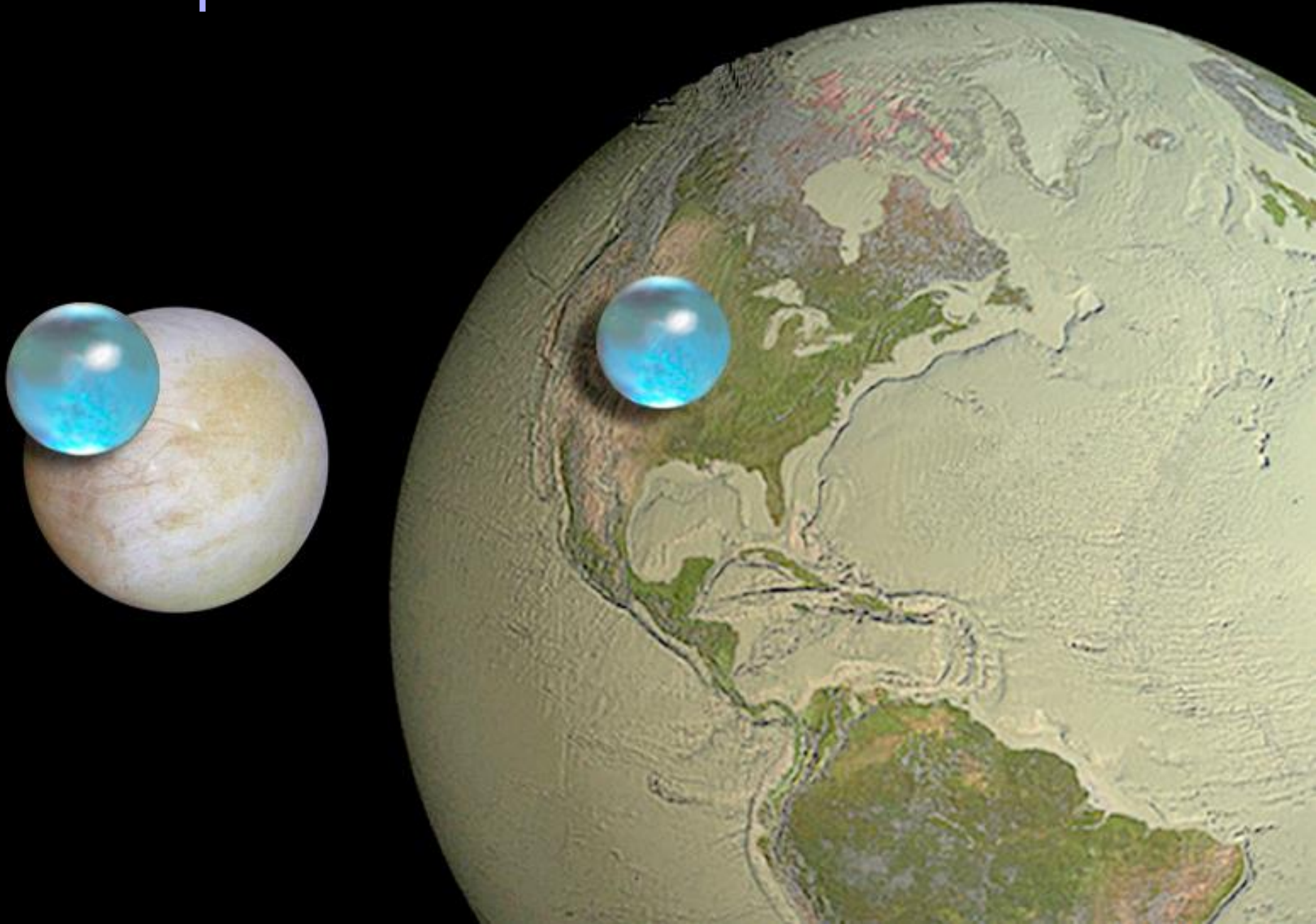


20 km

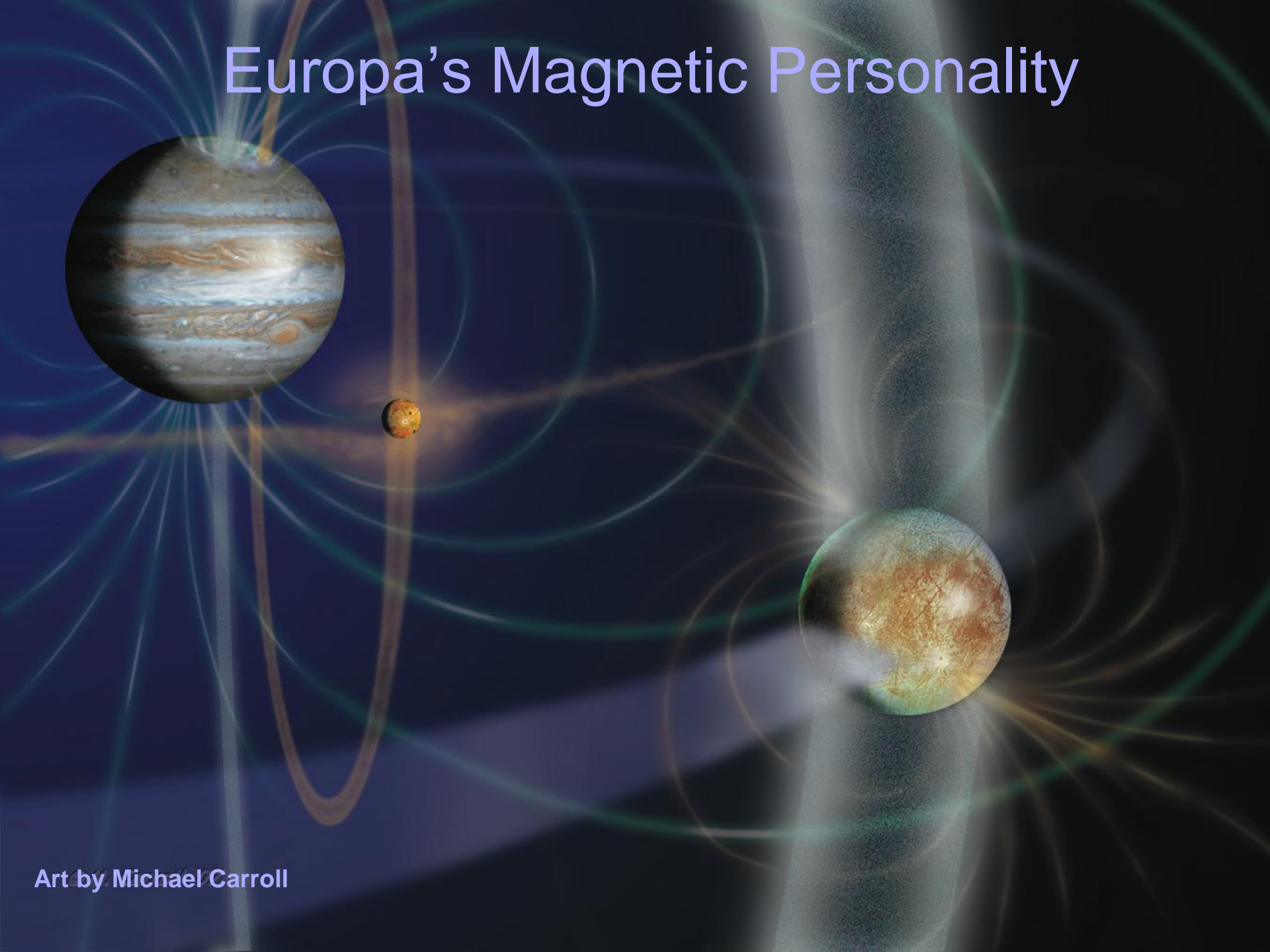
Europa's Interior



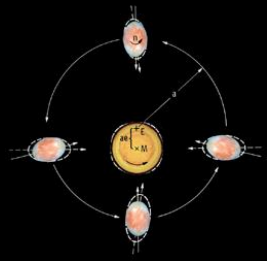
Europa Has 2x More Water than Earth



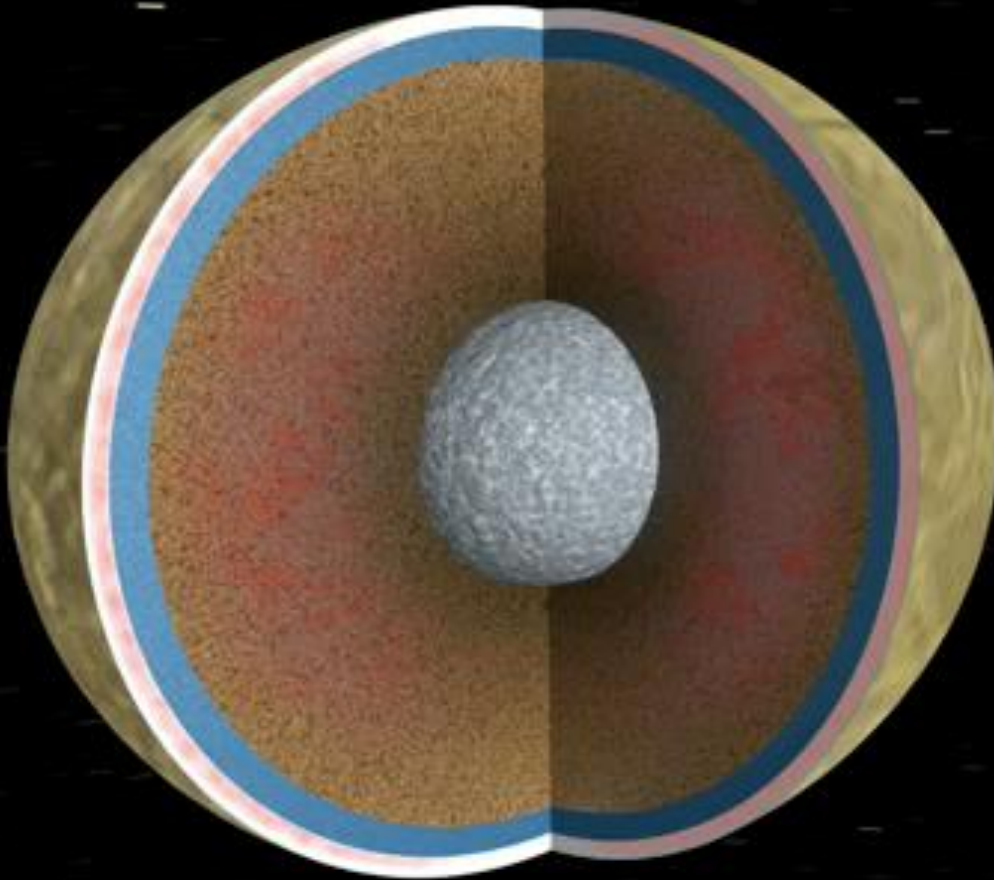
Europa's Magnetic Personality



Art by Michael Carroll



Tidal Flexing



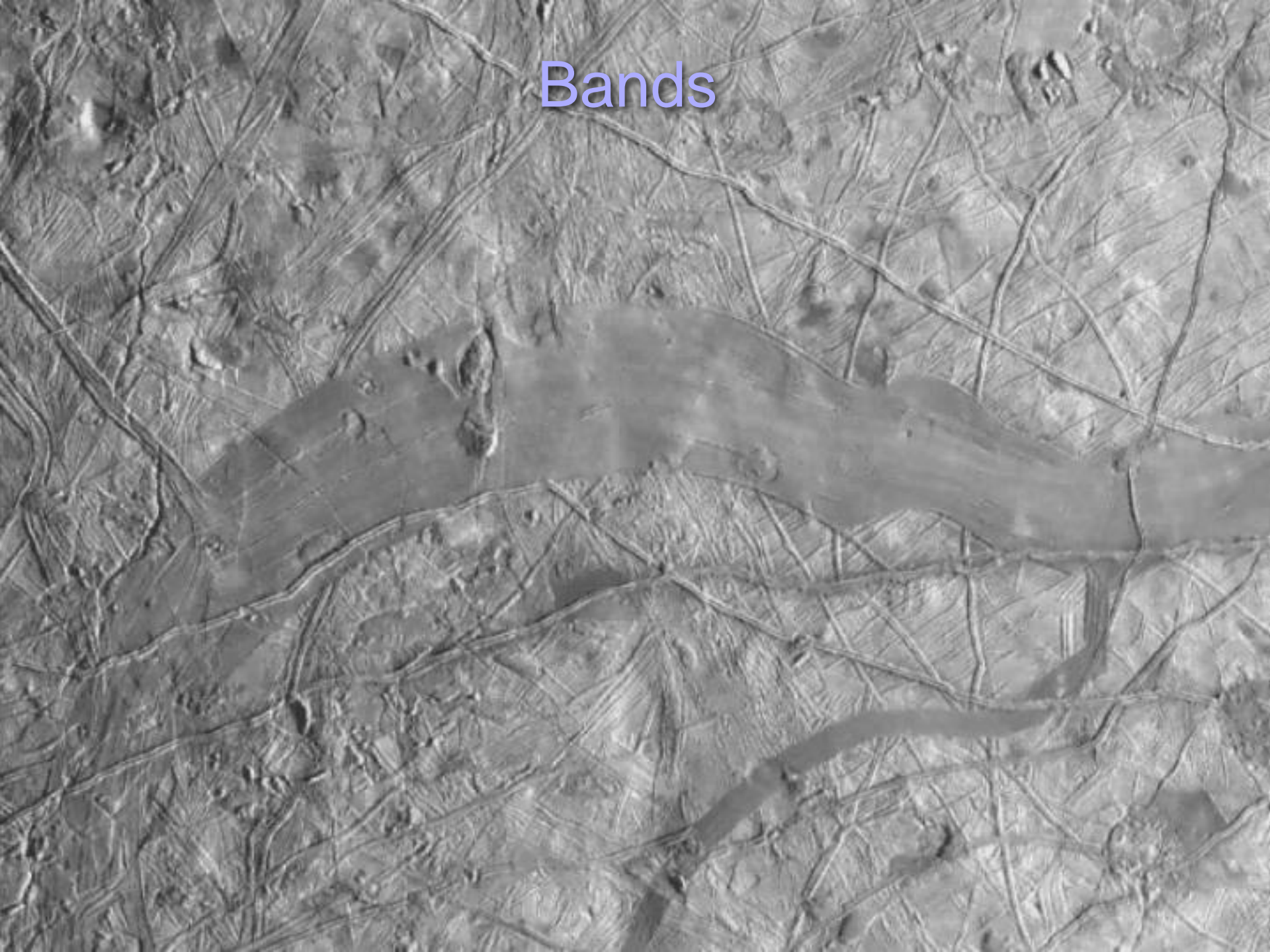
Ridges



Bands



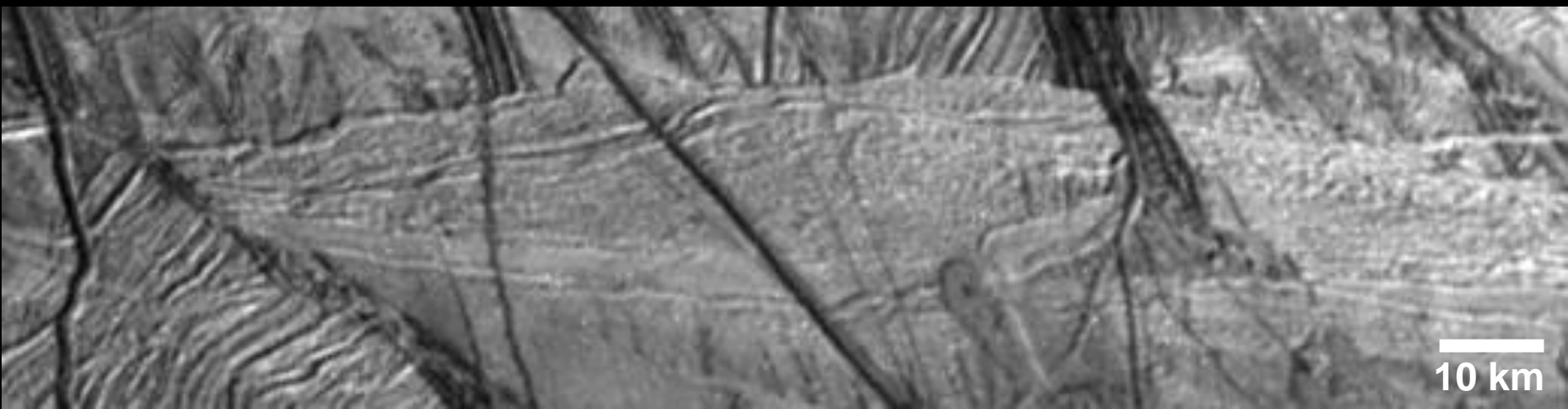
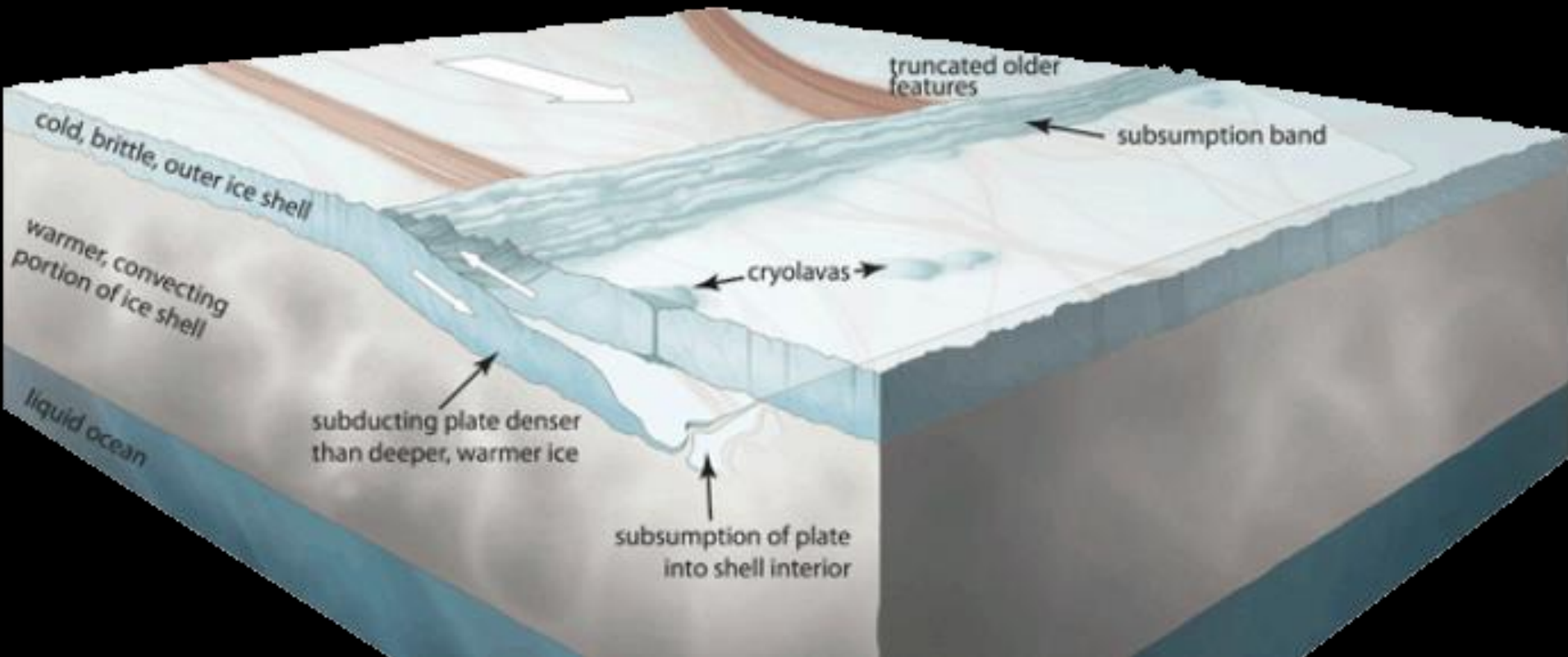
Bands





Bands

Subduction Zones?



Impacts


5 km

Pwyll

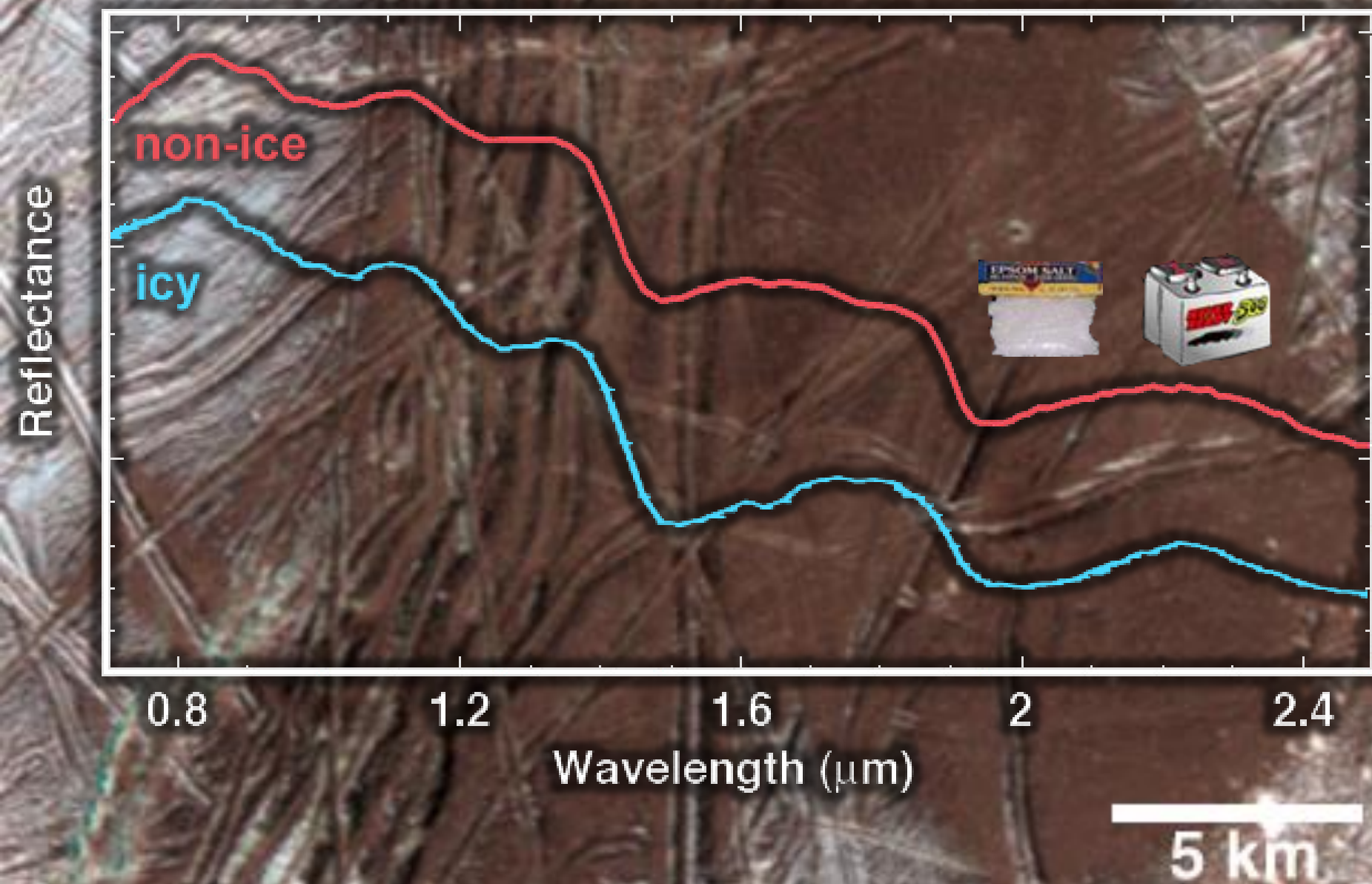
Impacts

10 km

Tyre



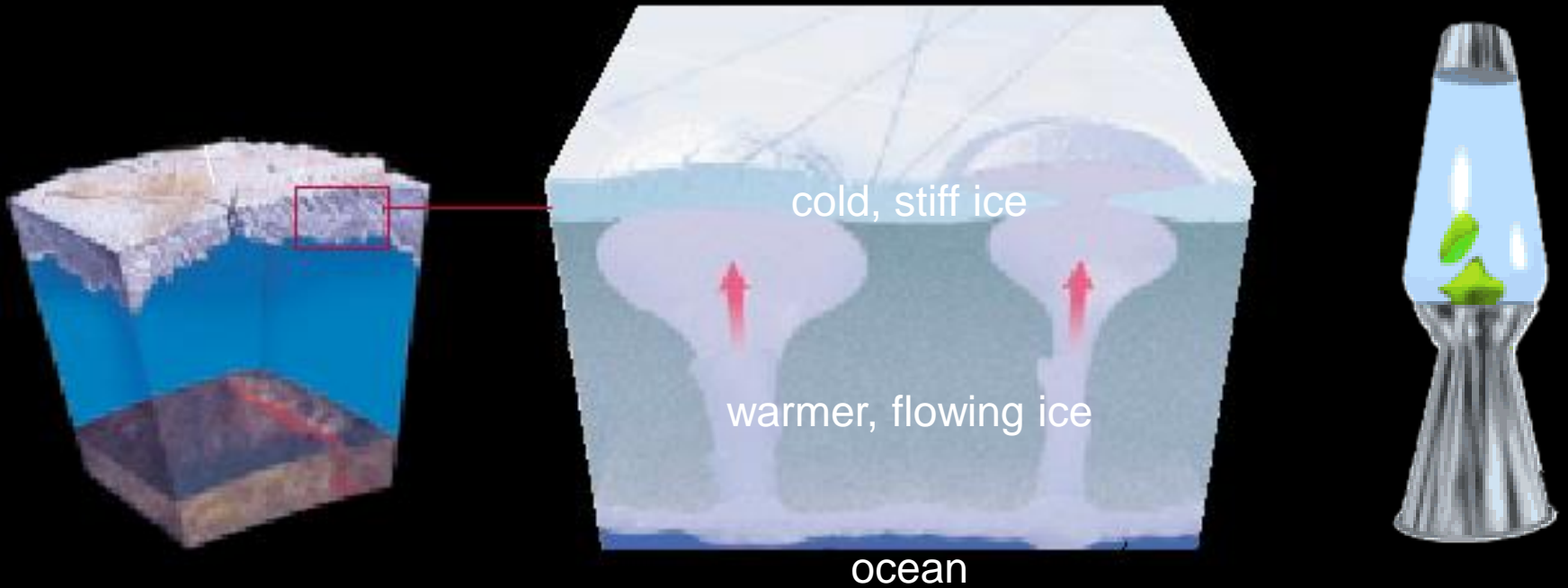
Dark Spots



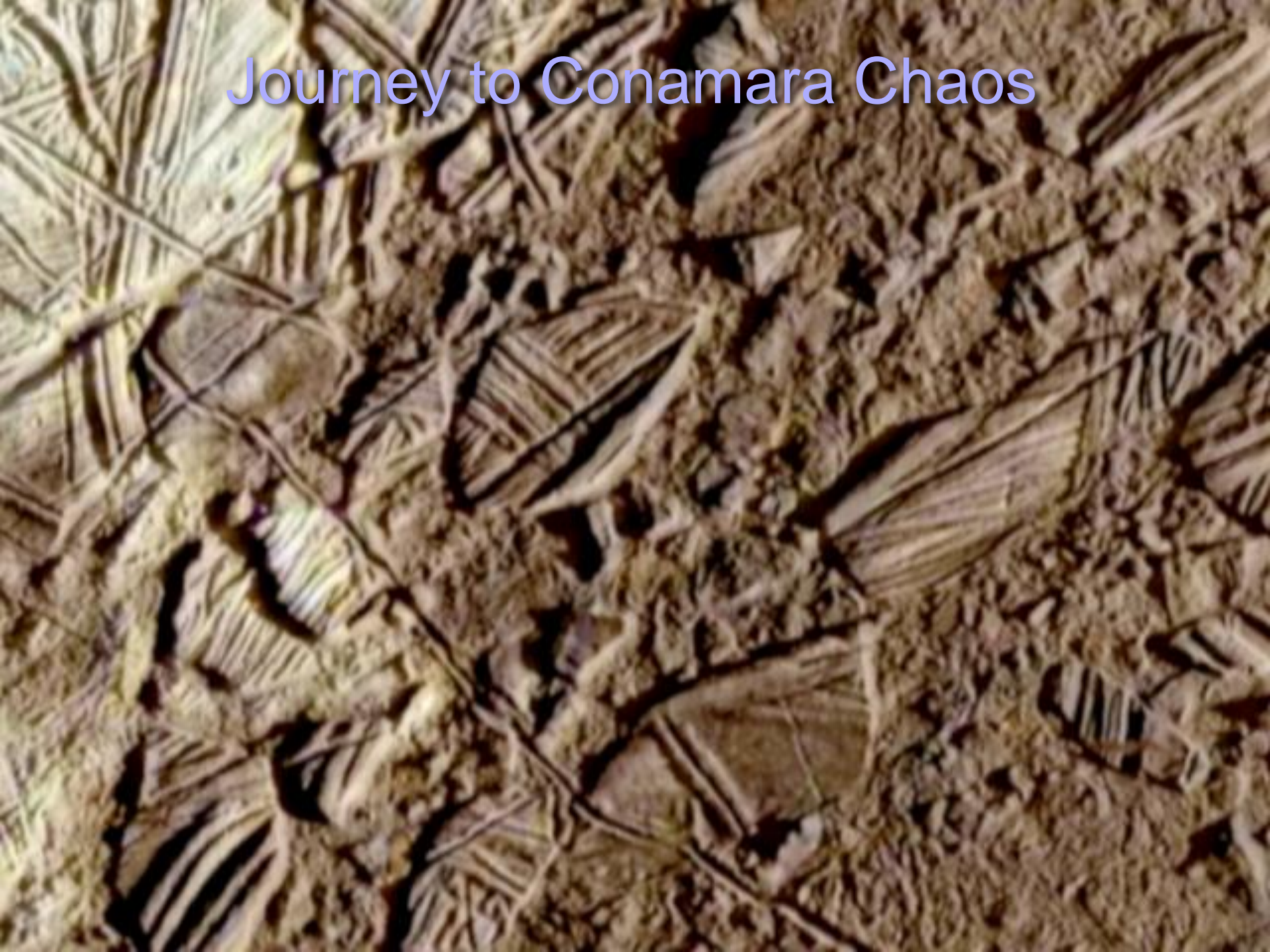
Lenticulae



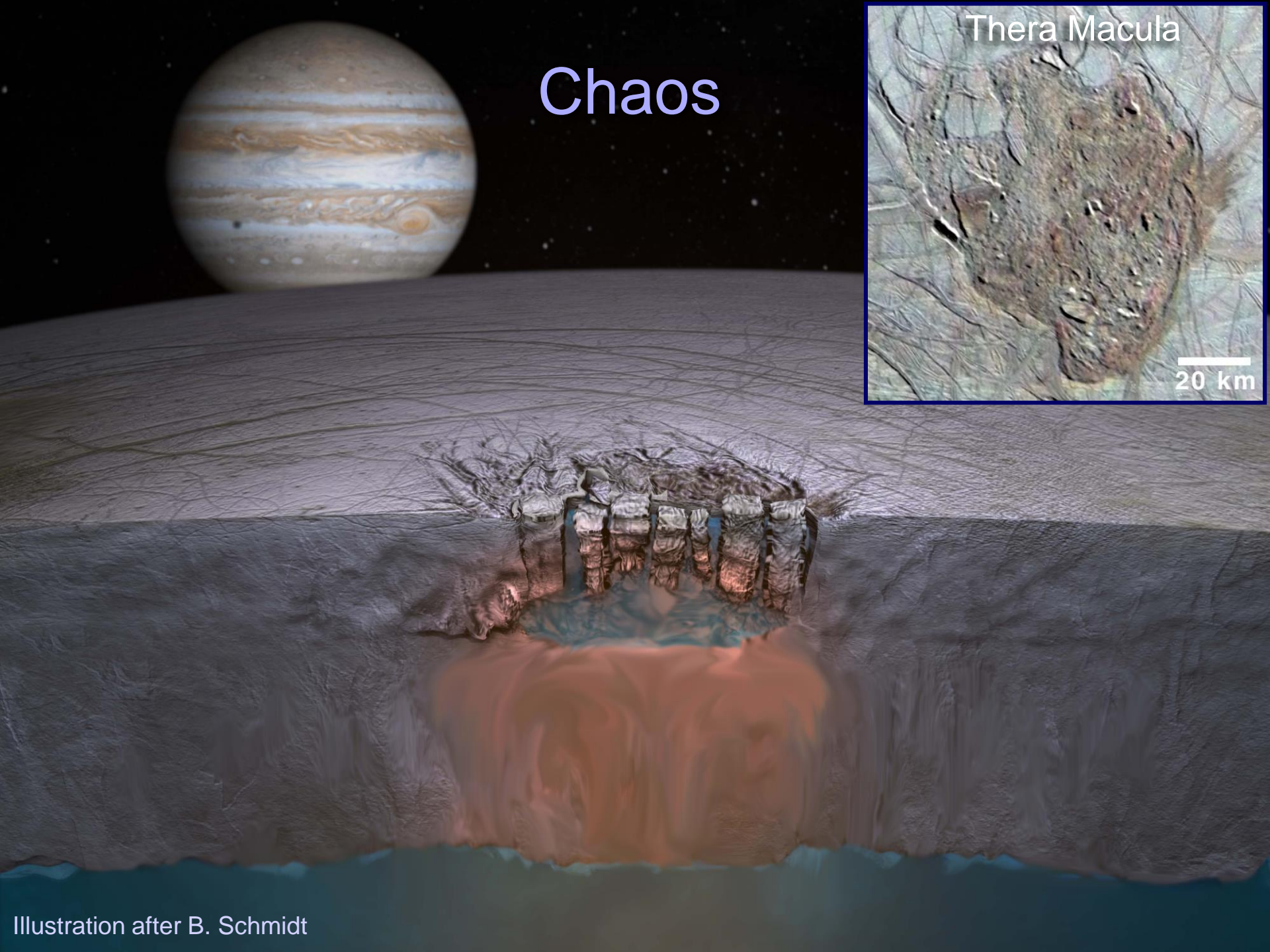
Icy “Lava Lamp”



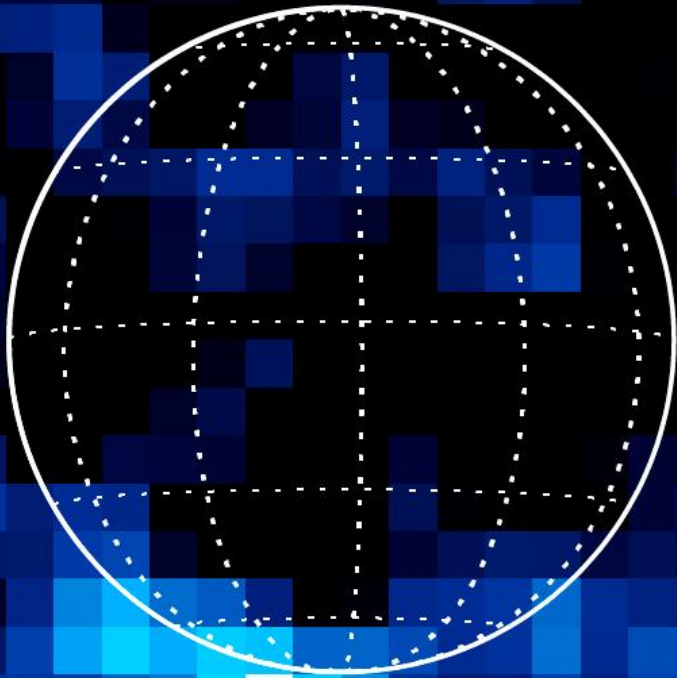
Journey to Conamara Chaos



Chaos



Plumes?



Hubble image



Artist's concept

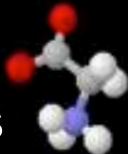
The Planetary Ingredients for Life



water



essential
elements



chemical
energy



stability



Ingredients for Life?



Water: *Much more than all of Earth's oceans*



Essential elements: *From formation and impacts*

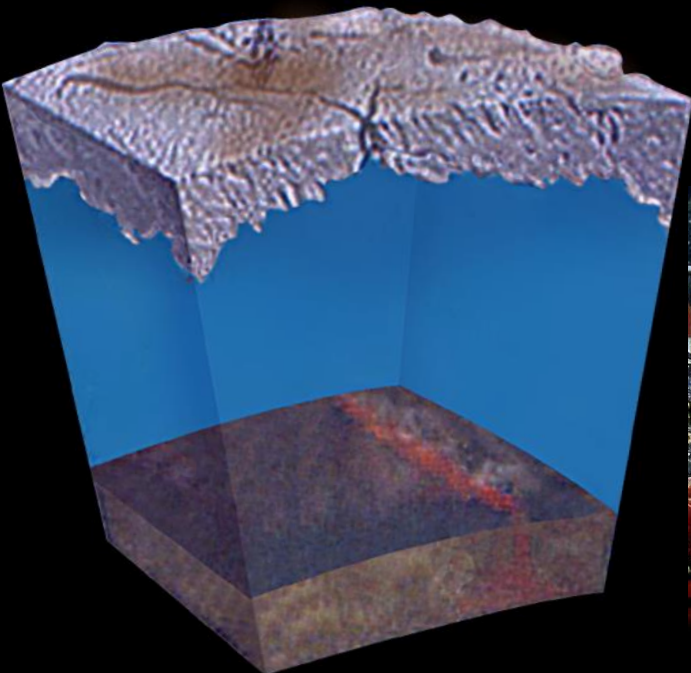


Chemical energy: *From above and below*

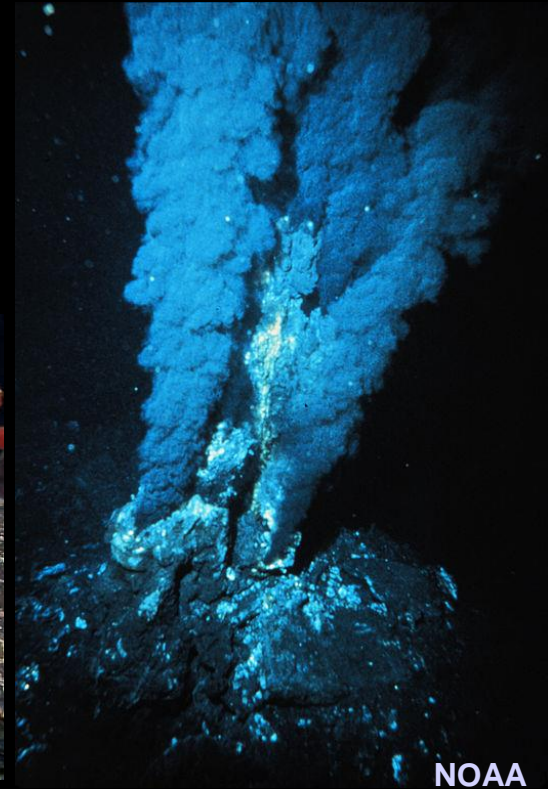


Stability: *"Simmering" for 4 billion years*

Europa's ocean



Earth's ocean floor

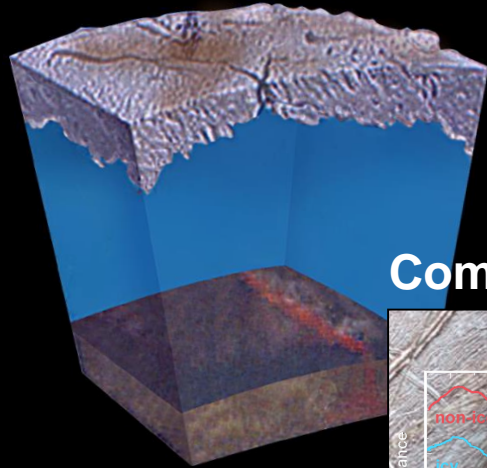




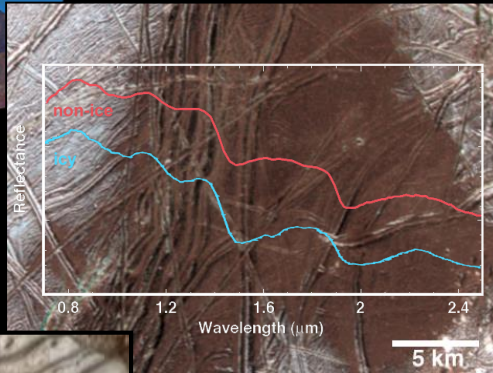
Europa Mission Science

Goal: Explore Europa to investigate its habitability

Ocean & Ice Shell



Composition



Geology



Reconnaissance



NASA-Selected Europa Instruments



MASPEX
Mass Spectrometer
sniffing atmospheric
composition

SUDA
Dust Analyzer
surface & plume
composition

ICEMAG
Magnetometer
sensing ocean
properties

PIMS
Faraday Cups
plasma environment

Europa-UVS
UV Spectrograph
surface & plume/atmosphere
composition

EIS
*Narrow-Angle Camera +
Wide-Angle Camera*
mapping alien landscape in
3D & color

MISE
IR Spectrometer
surface chemical
fingerprints

E-THEMIS
Thermal Imager
searching for hot spots

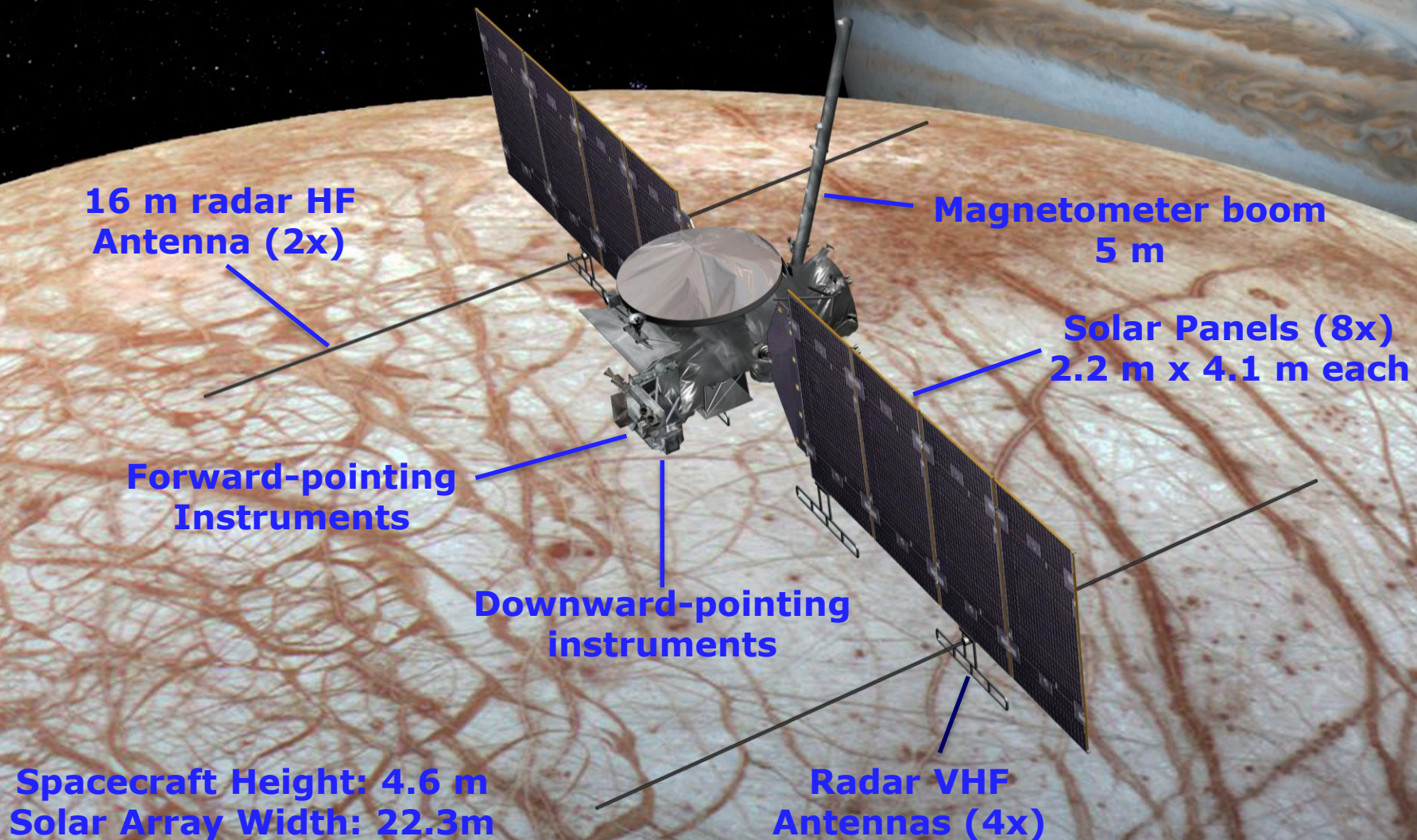
REASON
Ice-Penetrating Radar
plumbing the ice shell

Telecom System
Gravity Science
confirming an ocean

● Remote Sensing

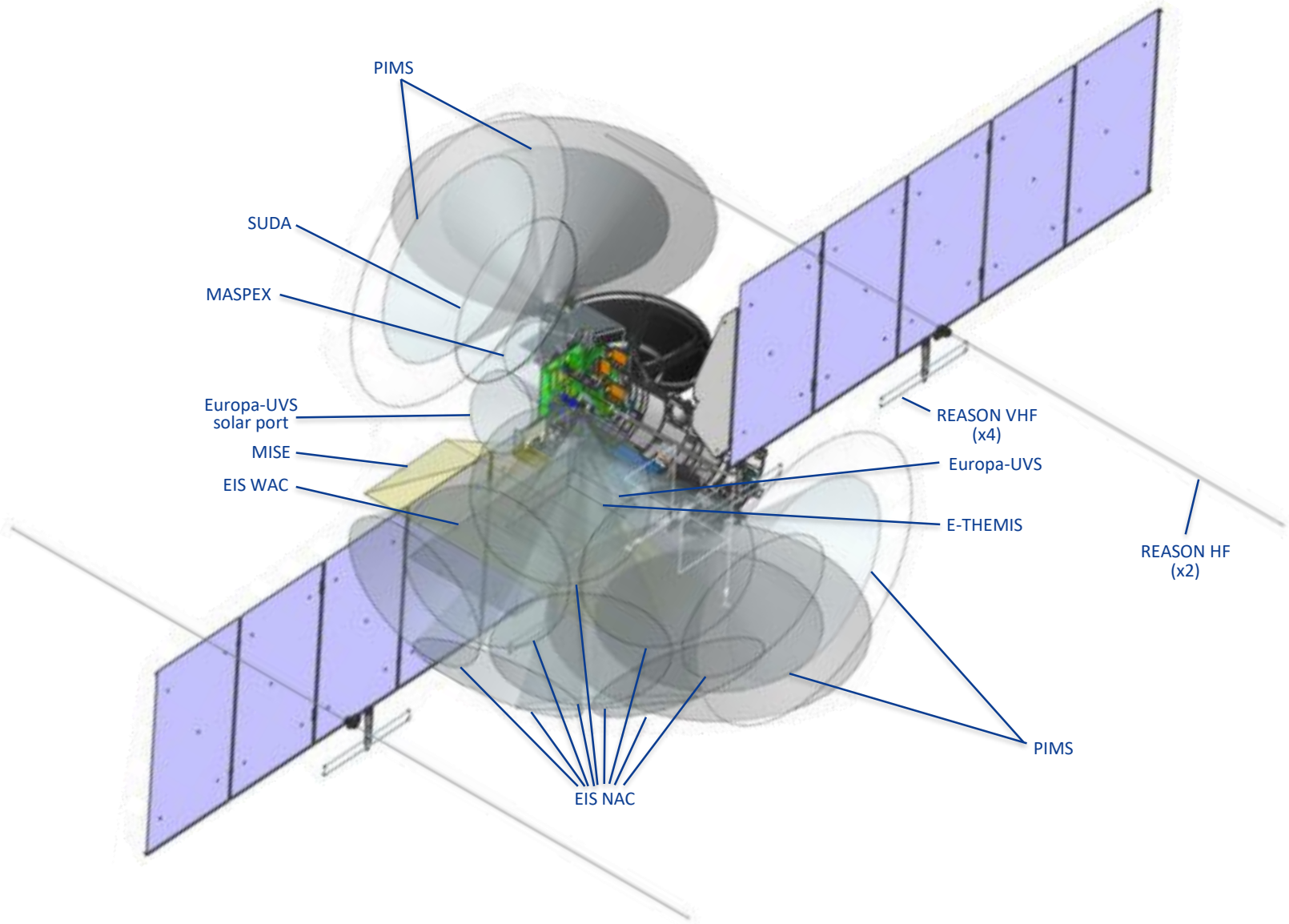
● In Situ

Europa Mission Concept



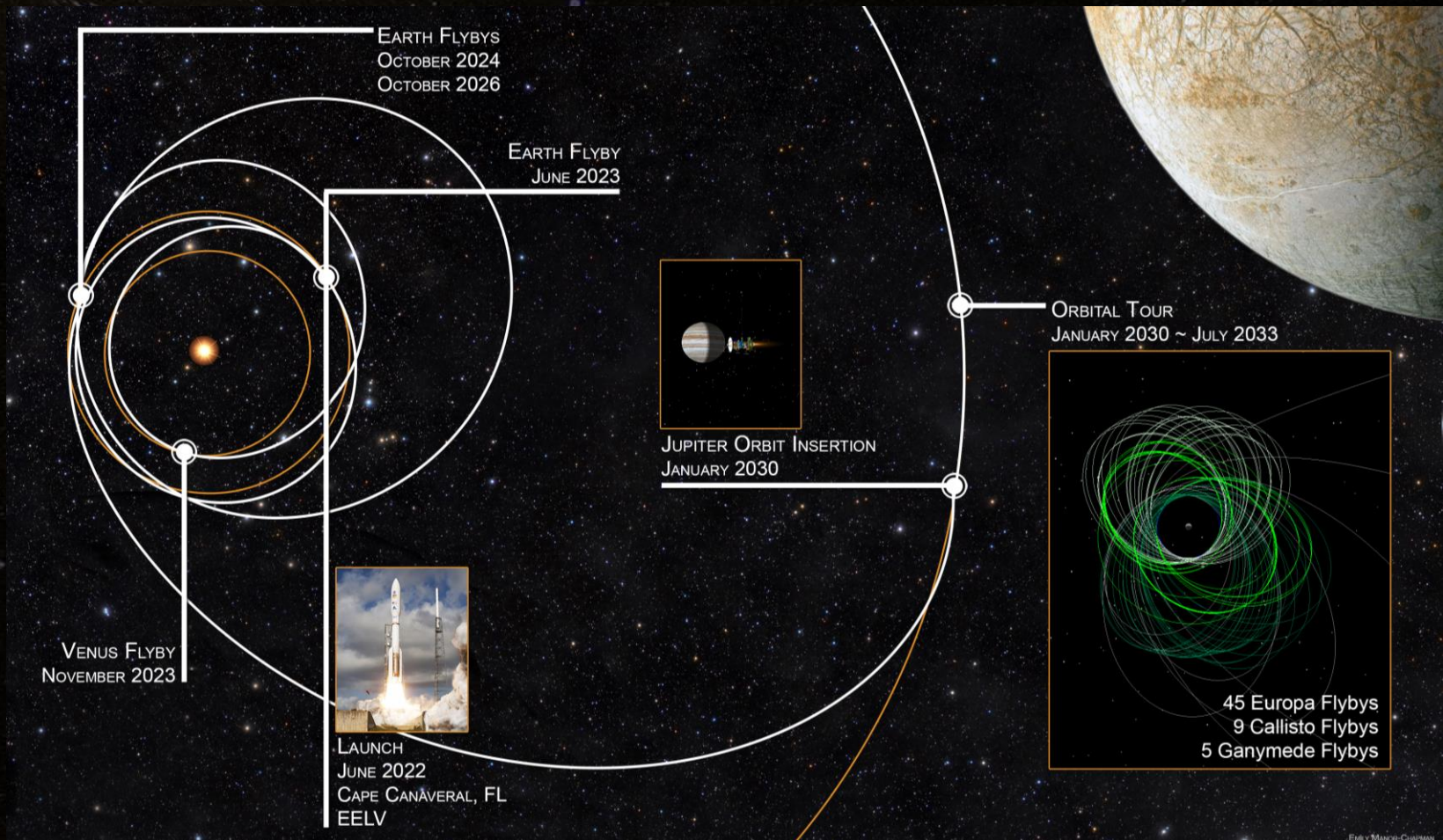
Pre-Decisional Information — For Planning and Discussion Purposes Only

Optimizing Instrument Placement



EEEGA Interplanetary Trajectory

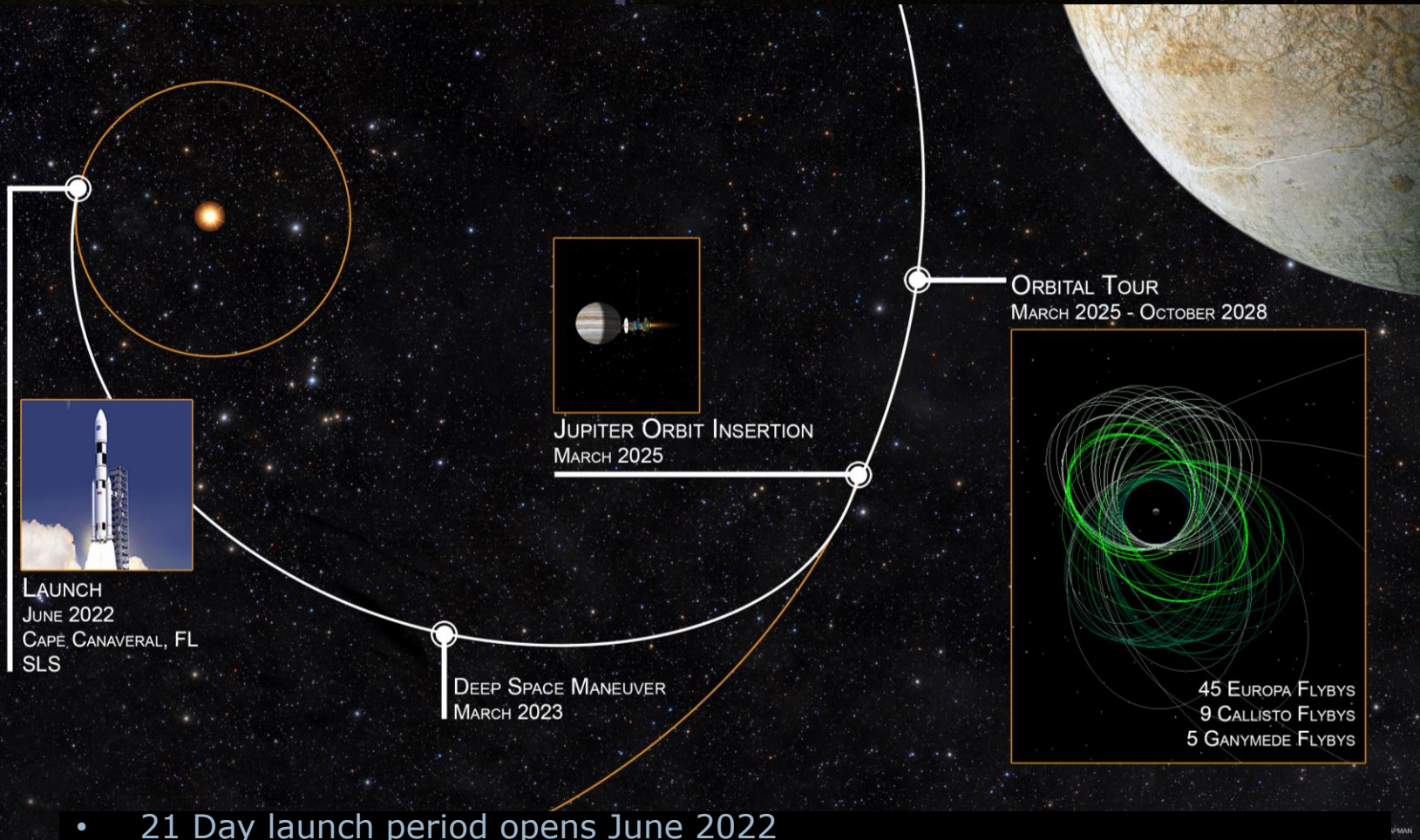
Conventional Rocket – Delta-IV/Falcon Heavy)



- 21 Day launch period opens May 2022
- Earth/Venus/Earth/Earth Gravity Assist
- Arrive Jovian System January, 2030 (7.5 Years)

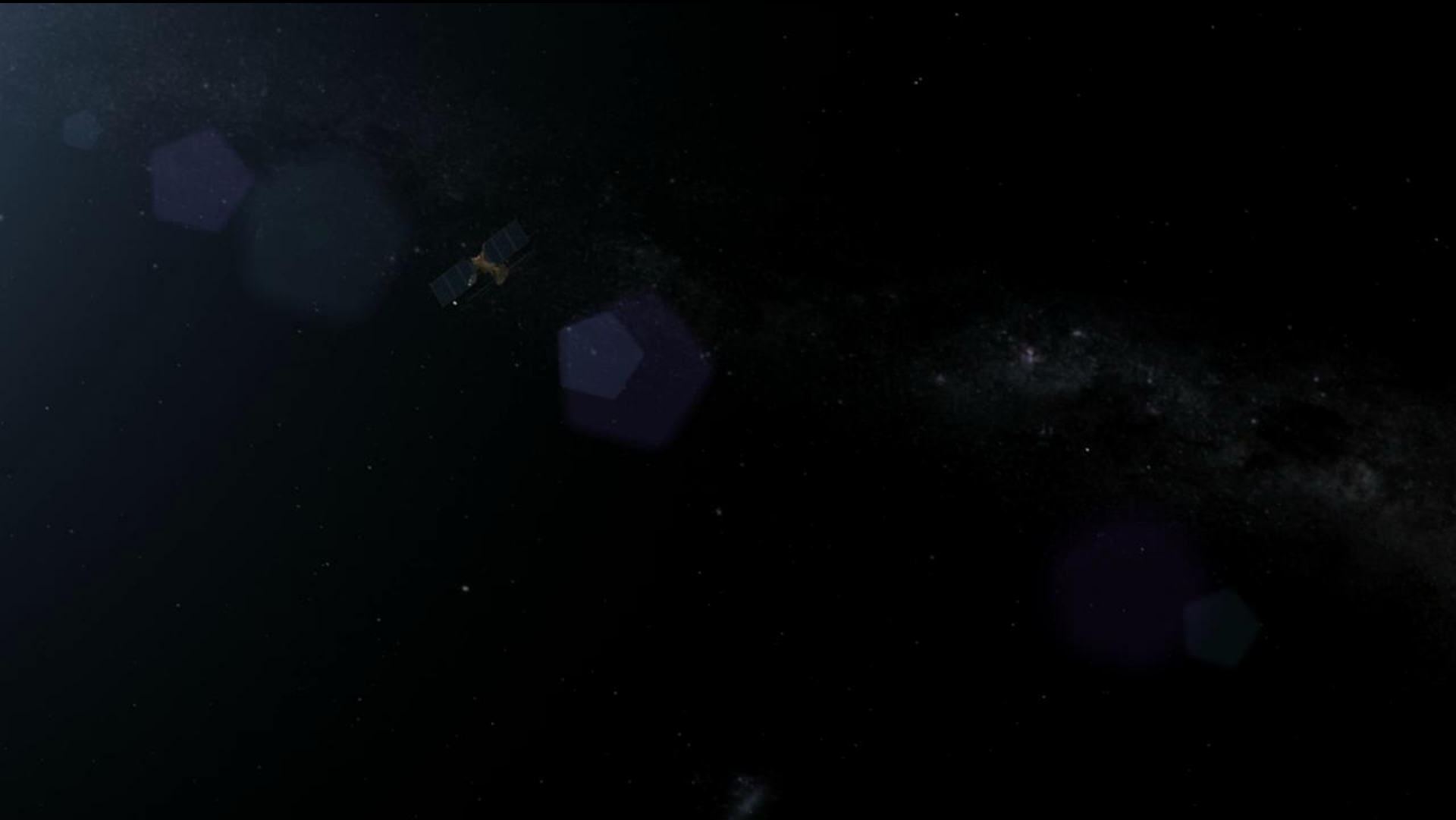
Direct-to-Jupiter Trajectory

SLS Rocket – Space Launch System



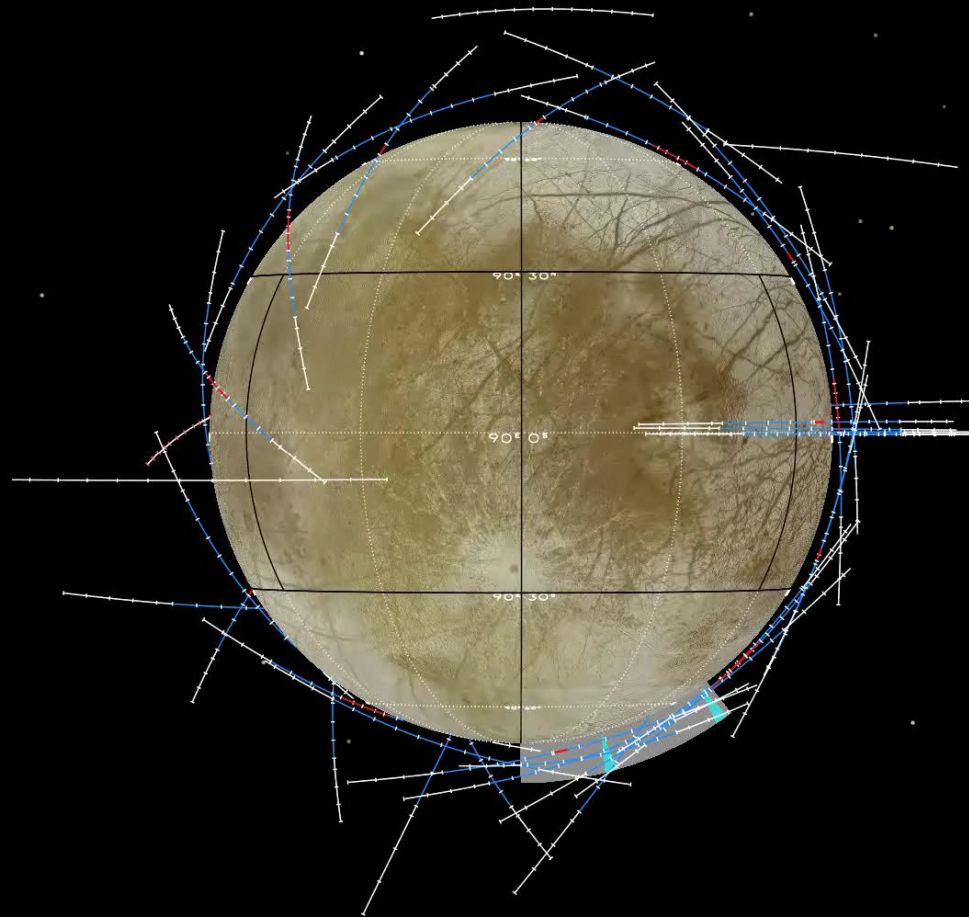
- 21 Day launch period opens June 2022
- Arrive Jovian System March, 2025 (2.7 Years)

Flying by Europa



A Global Web of Fly-bys

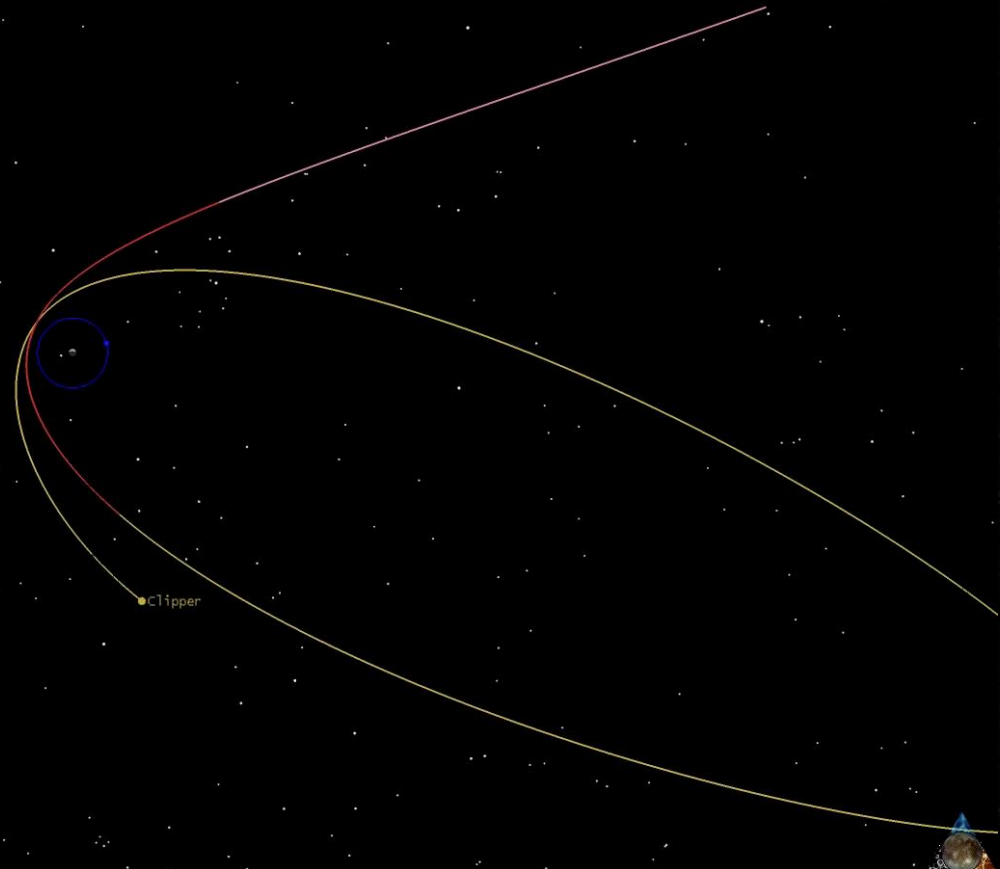
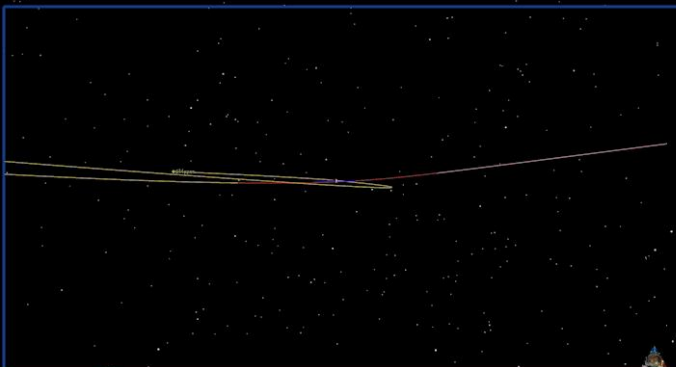
13F7-A21 Trajectory





Example Jovian Tour

- Jupiter Approach
- Jupiter Orbit Insertion
- Transition to Europa Science
- Europa Anti-Jupiter Hemisphere
- Europa Illuminated Hemisphere Transition
- Europa Sub-Jupiter Hemisphere
- Solar Eclipse



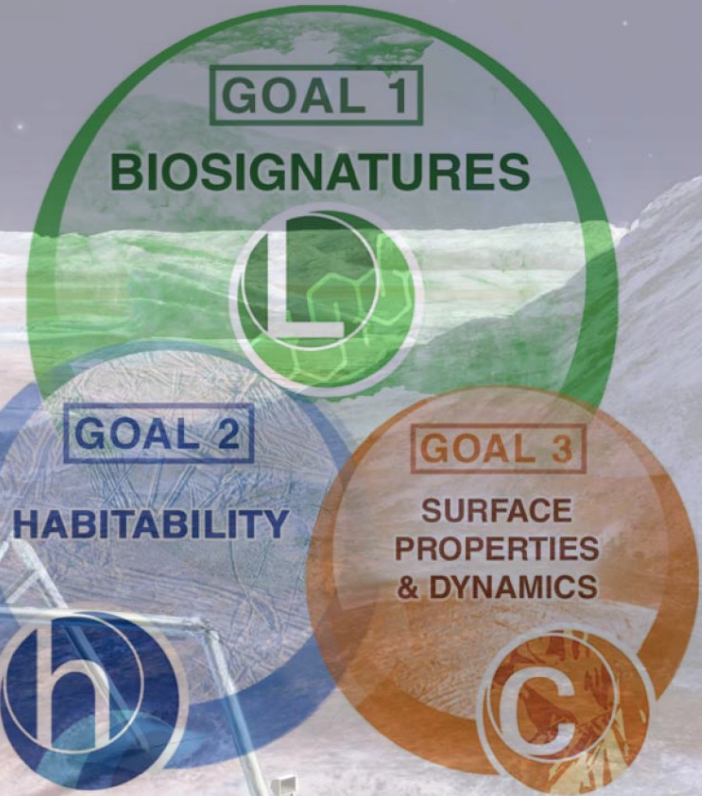
Europa Lander Concept

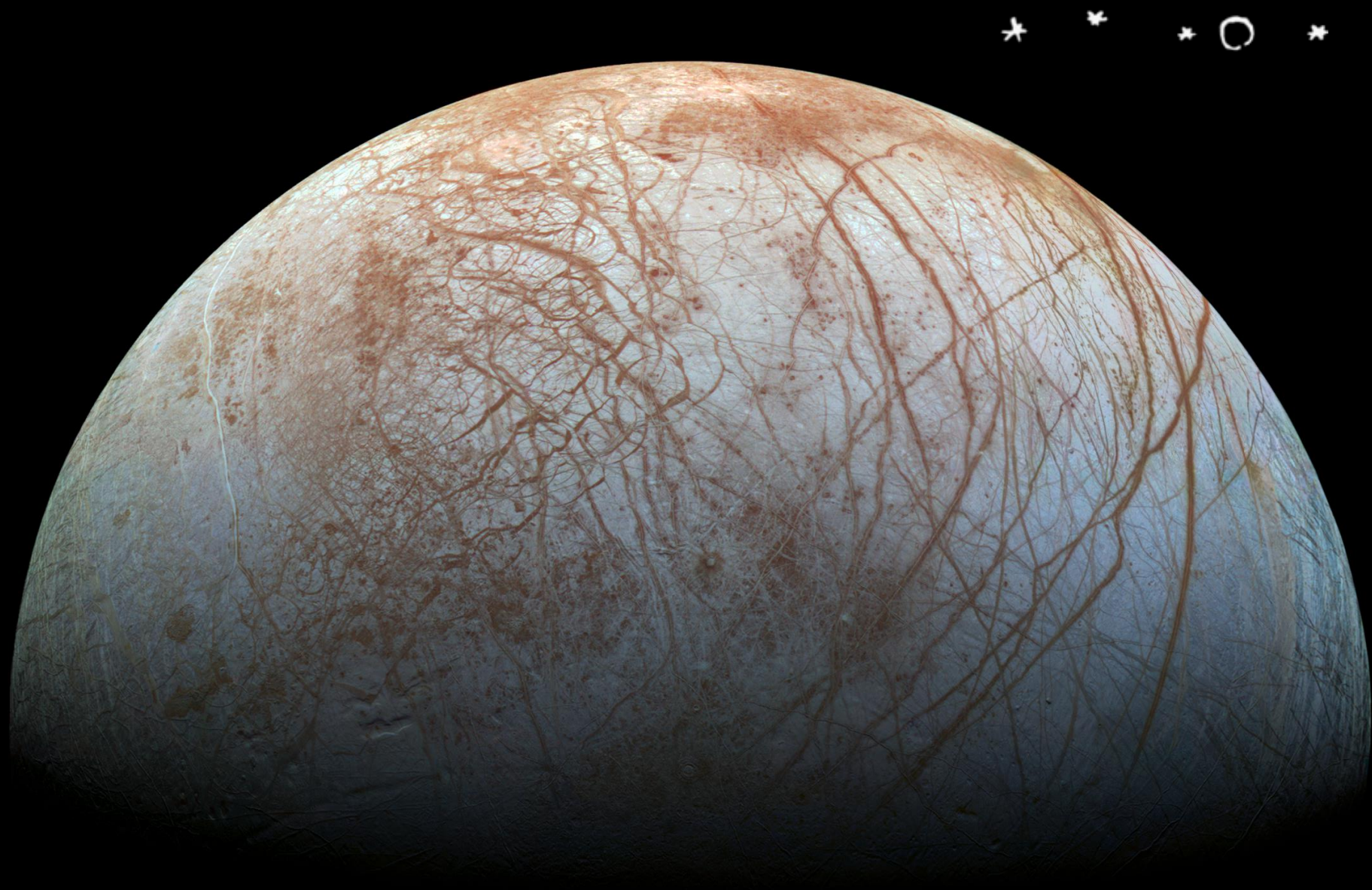


Pre-Decisional Information — For Planning and Discussion Purposes Only

Europa Lander Concept: Science Goals

1. Search for evidence of life on Europa
2. Assess the habitability of Europa via *in situ* techniques
3. Characterize the surface and subsurface to enable future robotic exploration







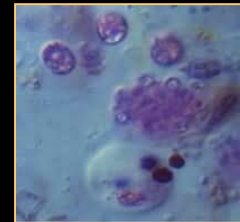
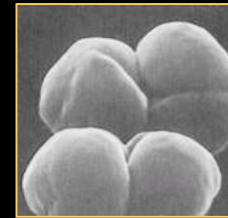
<http://www.nasa.gov/europa>



<http://www.nasa.gov/europa>

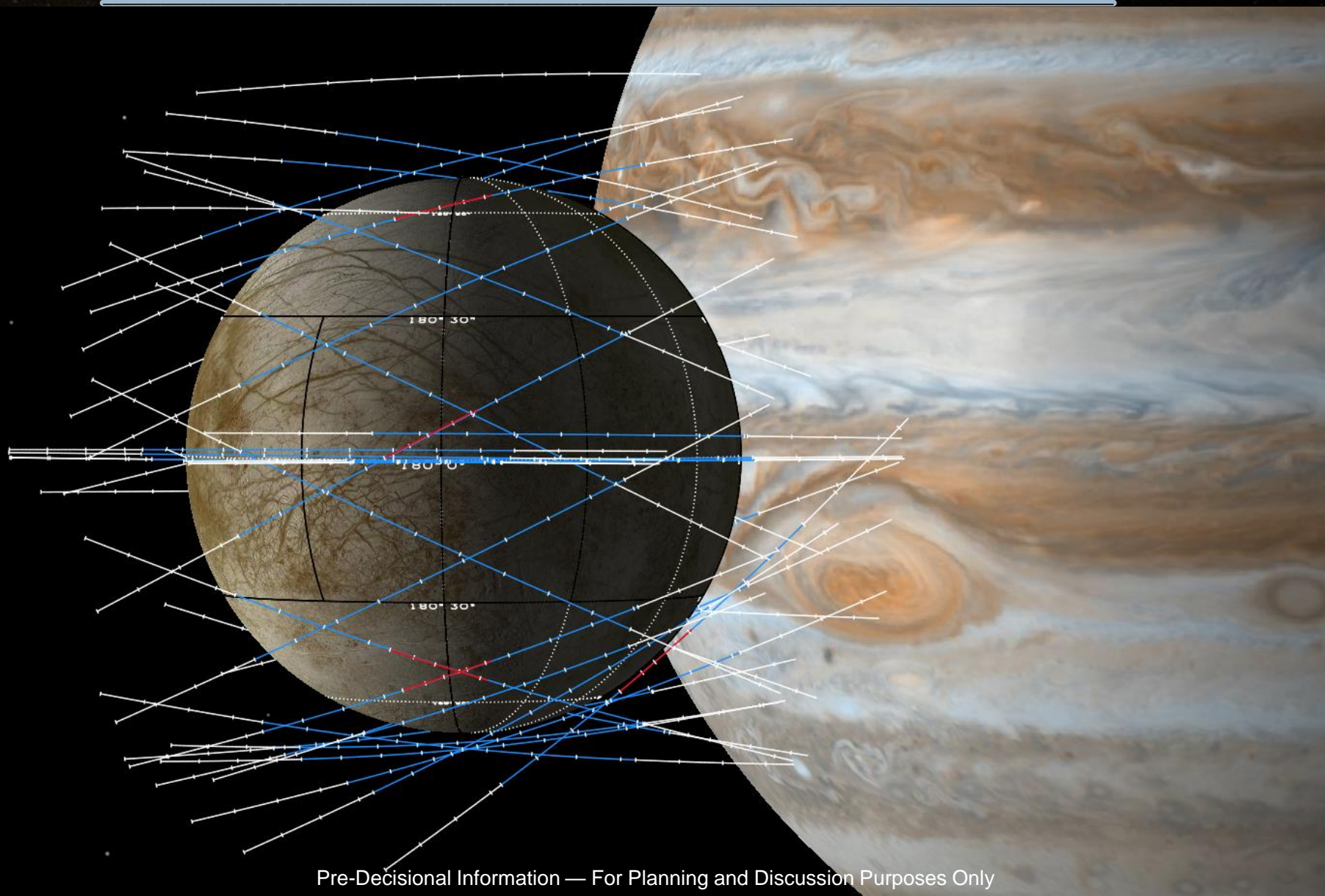
Some Reactions That Can Power Life

- Photosynthesis (plants):
 - ✧ $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{sugar} + \text{O}_2$
- Aerobic respiration (animals):
 - ✧ $\text{sugar} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$
- Iron oxidation:
 - ✧ $2\text{Fe}^{2+} + \frac{1}{2} \text{O}_2 + 2\text{H}^+ \rightarrow 2\text{Fe}^{3+} + \text{H}_2\text{O}$
- Methanogenesis:
 - ✧ $\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$
- Sulfur reduction or oxidation:
 - ✧ $\text{H}_2\text{SO}_4 + 4\text{H}_2 \rightarrow \text{H}_2\text{S} + 4\text{H}_2\text{O}$
 - ✧ $\text{CO}_2 + 2\text{H}_2\text{S} \rightarrow \text{CH}_2\text{O} + 2\text{S} + \text{H}_2\text{O}$



Chemosynthesis: Chemical reactions can power life, in the absence of sunlight (without photosynthesis)

A Global Web of Fly-bys



Pre-Decisional Information — For Planning and Discussion Purposes Only